WDM for Military Platforms

April 18 - 19th, 2000

Micro-WDM for Reconfigurable Military Information Systems

William P Krug
The Boeing Company
Seattle, WA
william.p.krug@boeing.com

Boeing

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **18 APR 2000**	2. REPORT TYPE **N/A**	3. DATES COVERED **-**

4. TITLE AND SUBTITLE **Micro-WDM for Reconfigurable Military Information Systems**	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **The Boeing Company Seattle, WA**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR’S ACRONYM(S)
	11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES
DARPA/MTO, WDM for Military Platforms Workshop held in McLean, VA on April 18-19, 2000, The original document contains color images.

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**UU**	**16**	

Micro-WDM for Reconfigurable Military Information Systems

- Platforms and WDM
- Micro-WDM Comparison
- Switch Comparison
- Roadmap

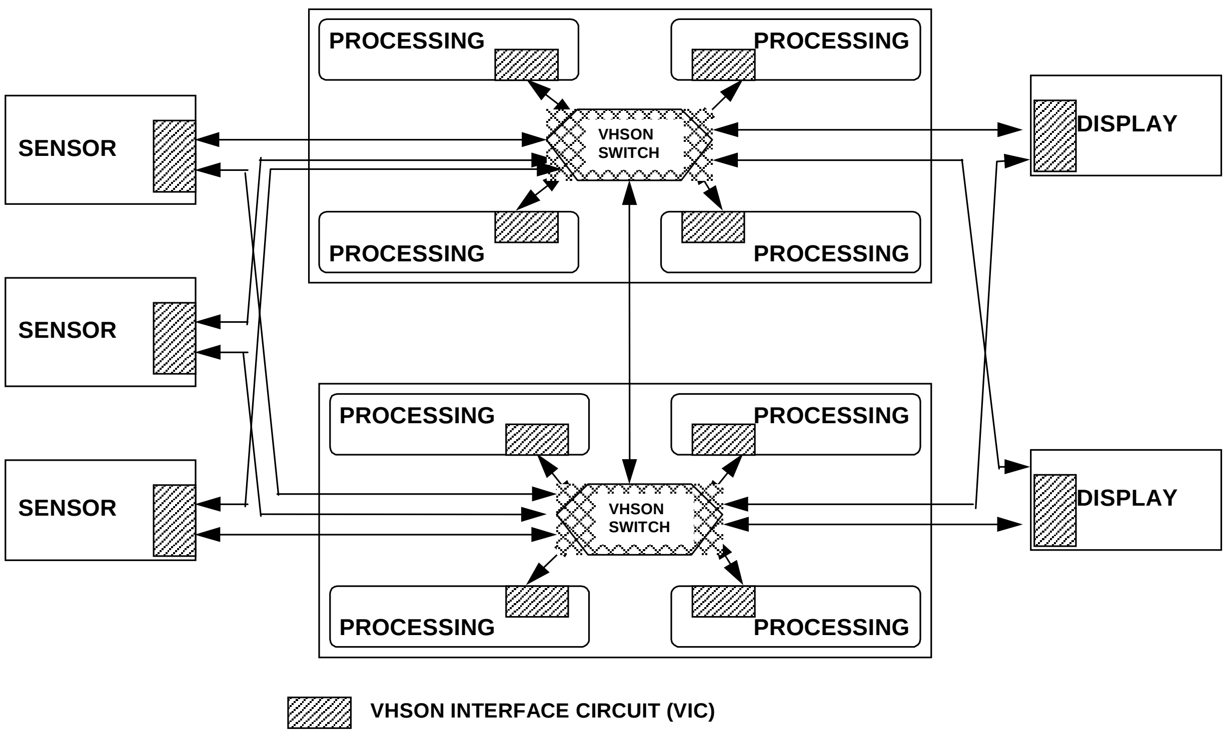
Micro-WDM for Reconfigurable Military Information Systems

- **A Potentially Ubiquitous Technology**
  - **Space: Space-Based Radar**
  - **Air: UCAV**
  - **Ground: Telco**
  - **Sea: Advanced Networks**

- **System Benefits Include:**
  - **Reduced Size, Weight, Power, Parts Count, System Complexity**
  - **Growth/ Upgrade Facilitation**
  - **Increased Bandwidth, Fault Tolerance, System Flexibility**

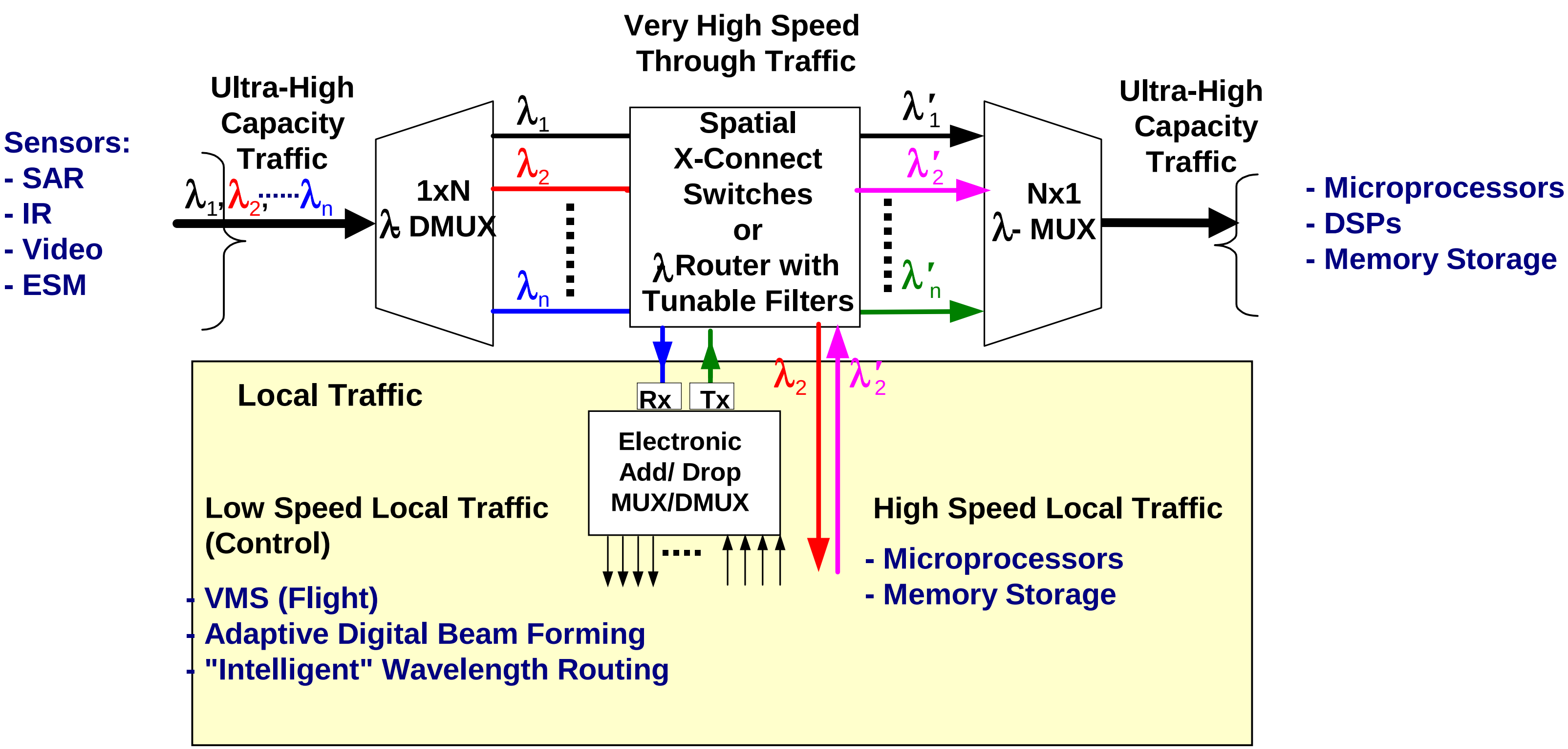
Configurable High Speed Optical Networks (Near Term)

- Tactical Aircraft
  - High Bandwidth Fiber Optic I/O for Remote Sensor Fusion, Processing, Storage, and Control
    - IR (eg. hyperspectral), Video, SAR, ESM
    - Microprocessor and Memory
    - Flight Control (Migration from Electrical to Optical)
  - Optical Routed Paths (Mesh) (eg. Monterey/ Cisco)
    - Electrical SEM-E Circuit Switch Upgrade
- Scalable, Optical Routable Paths for “Very High Speed Optical Networks” (VHSON)



Configurable Optical Wavelength and IP Network

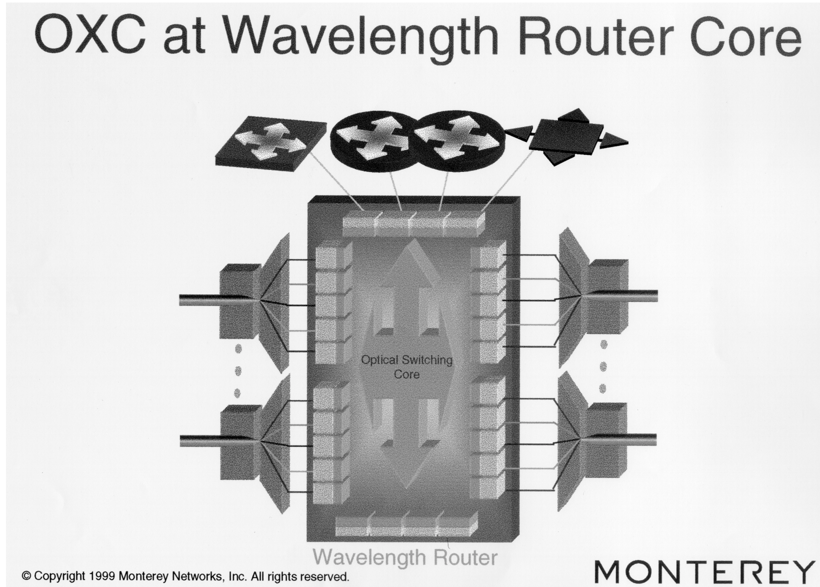
(Notional)



Configurable optical wavelength and IP networks will:

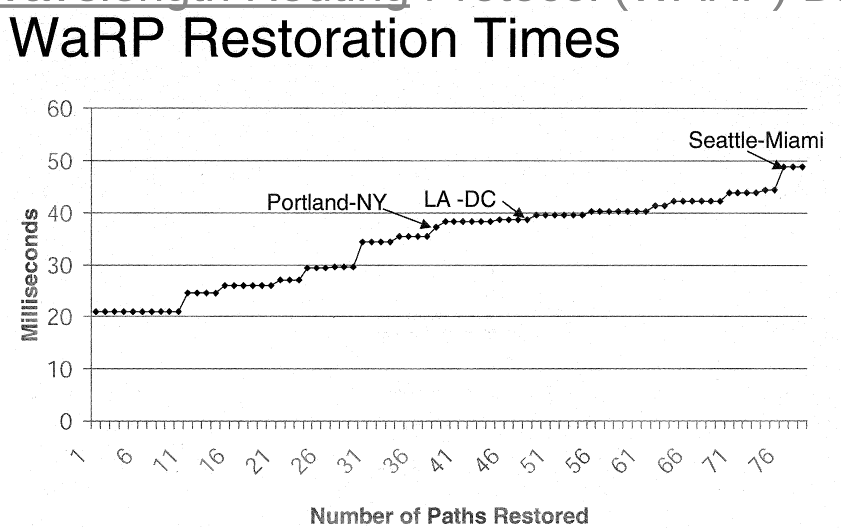
- switch low speed packets of IP data
- establish wavelength circuits or paths for high speed IP data
- establish paths in real-time

Power Dissipation of This Wavelength Router Will Be Greatly Reduced with an Optical Switch Core !



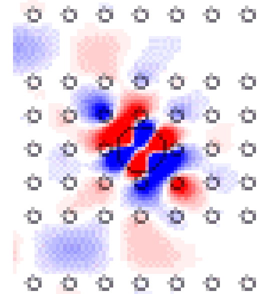
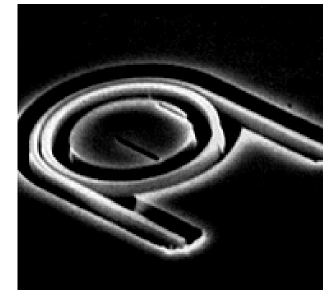
/ Cisco

Dynamic Wavelength Routing Protocol (WARP) Distributed Mesh



APPROVED FOR PUBLIC RELEASE, DISTRIBUTION UNLIMITED

Micro-WDM Technology for Reconfigurable Network Systems

Technology	COTS Array WG Device	Photonic Bandgap (PBG)	Microresonators (MR)
State-of-Art R&D	 Photonic Integration Research Inc.	 Joannopoulos et. al. (MIT) theory & exp.	 Nanovation Tech. Inc. S. T. Ho et. al.
Maturity	64 Channel Devices Available	Patents, 10 yrs. R&D 1 channel filter 5 yr. est. avail.	Patents, 10 yrs. R&D few channel filter avail. today
Insertion Loss	8 dB	3-4 dB (from fiber)	3-4 dB (from fiber)
Crosstalk	22 dB	TBD	TBD
Potential Channel Separation (1500 nm)	50 GHz	< 50 GHz	< 50 GHz
Size	10 cm x 5 cm x 2 cm	1 μm^3 (fiber driven)	1 μm^3 (fiber driven)

Approaches to Micro-WDM

Photonic Crystals with Photonic Bandgaps (PBG)

Approach	Technology	Advantages
PBG microcavity filters in series (see Fan et al, *Opt. Express*, 3, p.4, 1998 for example)	Photonic crystal of dielectric rods or PBG air bridge in Si	• Very large Q cavities little crosstalk between channels • Tolerance to fabrication imperfections • Very small $\sim(\lambda/2n)^3$

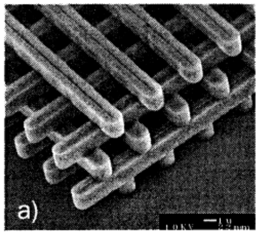
Microresonators (MR)

Approach	Technology	Advantages
• Extension of high density integrated optics with large Δn	Microresonators • Nanovation • NWU, MIT	• Commercially available in few element arrays

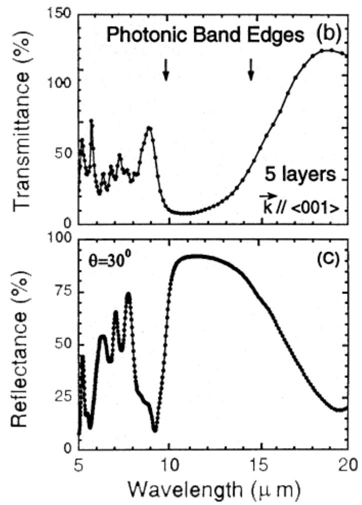
Photonic Crystal Super- Prisms

Examples of Photonic Band Gaps

Creation of a 3-D Silicon Photonic Crystal

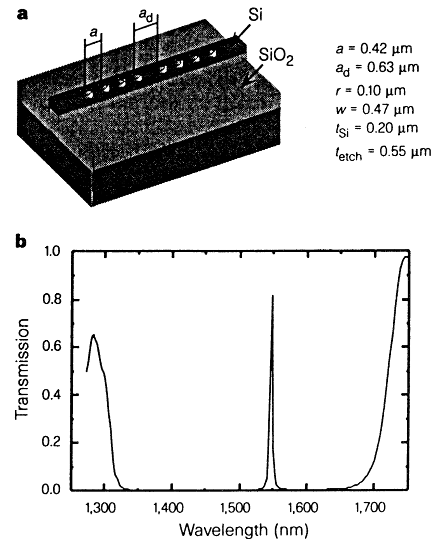


Lin Figure 1. (a) SEM image of a 5-layer 3-D photonic crystal built on silicon. The pitch between adjacent rods is 4.2 μm. (b) A transmission spectrum taken from the 5 layer 3-D crystal. (c) A reflectance spectrum taken from the same sample.



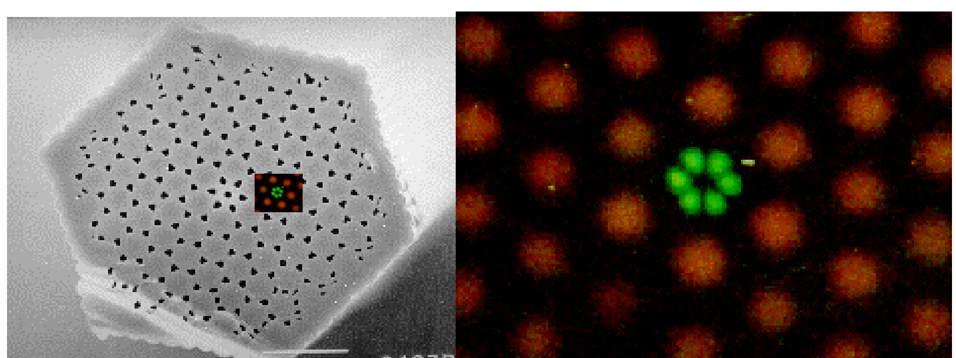
Shawn-Yu Lin and J.G. Fleming, Sandia National Laboratories,
Optics and Photonic News / p. 35, December 1998

Photonic Bandgap Filter in Optical Waveguide



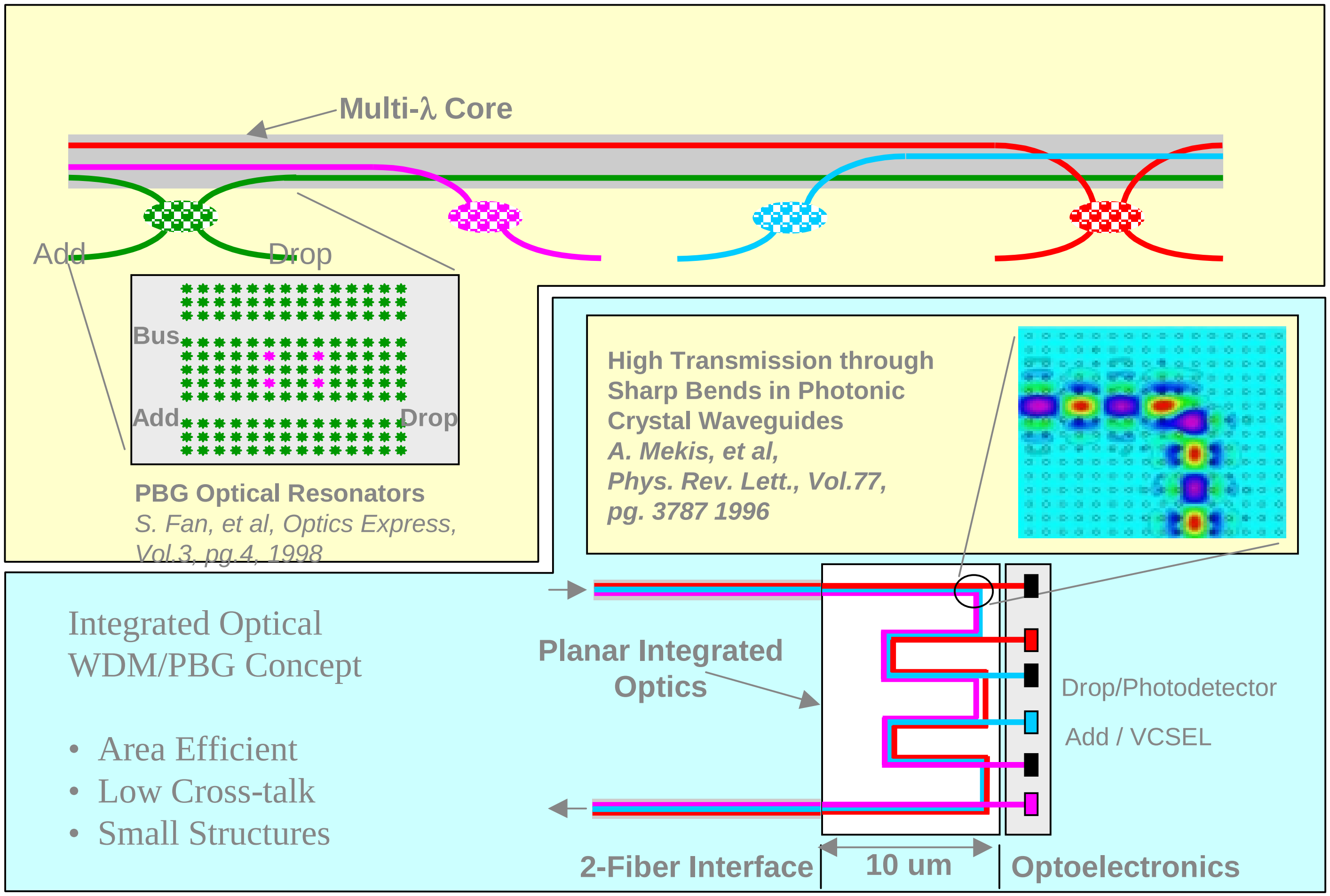
J.S. Foresi, P.R. Villineuve, et al., MIT,
Nature, vol. 390, pp. 143-5, 1997

Narrow 2-D PBG fiber waveguide: extra "defect" air core filters white light source



http://www.bath.ac.uk.Departments/Physics/opto/research.htm#pbg

Optical Fiber WDM/PBG Channel Add/ Drop Filter



Photonic Crystal Super- Prisms

Key Characteristics

- Highly anisotropic dispersion engineered "super-prism" material has exceptional angular wavelength dispersion characteristics (NTT, NEC)

- Angular dispersion that is 2 orders of magnitude larger than
    - gratings
    - prisms
    - PBG prism

    leads to 2 orders of magnitude shorter WDM elements

    - photonic crystal: 0.99 um and 1.00 um separated by 50^{o}
    - conventional crystal: 0.99 um and 1.00 um separated $< 1^{o}$

Fast Reconfigurable Switches for Micro-WDM

Parameter	Electrical	Optical
Ports	16	32
Data Rate	1 Gbps	> 2 Gbps
Media	fiber	fiber
Switch Fabric	ASIC or network processor	optical ADM or cross-connects
Matrix Latency	0.5 usec	N/A
Connect Time	3 usec	0.1 usec to 10’s usecs
Power Consumption	45 W per switch card plus transceivers	control only (<10 W)
Protocol	Fibre Channel	IP
Size	SEM-E card	.001” x .001” to 1’ x 1’
Markets	military platforms and telco	military platforms and telco

- **If 3 order of magnitude improvement in optical switching speed, then...**

Possible Electrical to Optical Switch Evolution

- **Fast Electrical Packet Switching for Low Port Counts (10’s)**
- **Medium Speed Optical “Circuit” Switching for High Port Counts (1000)**
- **Fast “MPLS” Optical Switching for “Visionary” Future Systems (TBD)**

Optical Switches* (in Decreasing Order of Switch Time)

Technology	Status	Max Array Size (N x N)	Switch Array Time	Insertion Loss	Latching
Bulk optomechanical (tilting mirrrors)	Product	1 x 16	15 msec	2 dB	Yes
Liquid crystal	Development	1 x 8	10 msec	3 dB	No
Bulk optomechanical (free space)	Development	576 x 576	5 msec	6 dB	No
Thermo-Optic	Product ?	8 x 8	1 msec ?	5 dB	No
Bubble/ TIR[1]	Product	32 x 32	1 msec ?		No
Microelectromechanical Systems (MEMS)[2] **(+/- 45^0)**	Development (for Optical Switches)	32 x 32	10's usec	3 dB	Yes
128 Level MEMS[3] **2N rather than N^2 Limits**	Development (for Optical Switches)	1000 x 1000	1 msec		
Microelectromechanical Systems (MEMS)[2,3] **(+/- 45^0)**	Development (for Optical Switches)	32 x 32	10's usec	3 dB	Yes
Microelectromechanical Systems (MEMS)[1] **(+/- 10^0)**	Product (for Digital Light Projectors)	500 K	10's usec	N/A	Yes
Lithium Niobate[4]	Development	8 x 8	0.1 usec	9 dB	No
Lithium Niobate	Product	4 x 4	0.1 usec	8 dB	No

1) Agilent
2) Lucent, OMM, ...
3) OMM,
4) EO Space, Lucent, ...

Micro-WDM Development Needs

- Define roadmap to large-scale Micro-WDM
- Trade and down-select micro-WDM technologies
- Perform basic device research
- Improve processing technology
- Develop optimum device designs
- Demonstrate passive WDM arrays
- Perform large-scale device integration
- Integrate high port density switches (near term) (and control)
- Demonstrate initial micro-WDM fast switch concepts
- Establish WDM and switch characterization, test, and measurement

Aerospace Role

- Assess system opportunities and benefits
- Assess & guide micro-WDM technology
  - Device modeling
  - Experimental characterization
  - Recommend optimum technology
- Initiate development team and identify “dual-use” apps
  - Universities, Component Manufacturers
    - passive high density arrays
    - fast switch elements
  - Network Companies
    - software control, management, reliability, optical path routing
- Execute WDM-based network demonstrations
    - integrate tunable Tx/Rx with passive arrays and switches
- Engineer WDM-based networks for deployed systems

Micro-WDM for Reconfigurable Military Information Systems

Goal: Mobile, wideband, scalable, protocol transparent, open systems

Technology Roadmap

Tx/Rx-AWG-MEMS-AWG-Rx/Tx

↓ 2 - 5 years

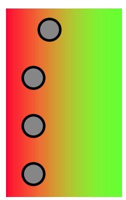
Tx/Rx-UR/PBG-MEMS-UR/PBG-Rx/Tx

↓ 5 -10 years

Tx/Rx-UR/PBG-SOA-AWG-Rx/Tx

Relative Risks

- Microresonator CDFs today
- PBG and super-prism CDF arrays
- Design and nano-fabrication
- Fast reconfiguration switches



Channel Drop Filter (CDF)

Related Challenges

- Tunable Sources and Detectors
- Array Cross Talk and Insertion Losses
- Packet or Channel Addressing
- Virtual Light Path Contention:
    - Wavelength Conversion
    - Optical Buffer Memories
    - Synchronization

Summary: 10 um Scale WDM Technology in F/O networks will bring trunking and routing of terabit/sec capacity optical fiber buses to mobile platforms. Fixed and tunable integrated add/ drop filters (and N x N optical cross-connects) reduce size and power, provide fault tolerance, reconfiguration, and mixed nets.

Approach

- **Smooth, scalable growth will result in migration from IP/ATM/SONET(ADM and DCS)/DWDM networks to MPLS/ optical mesh networks**
- **Tunable Tx and Rx will enable single part for WDM transport**
- **Wavelength routing switches will provision λ paths to resources**
- **May support mixed RF and digital networks in fault tolerant dual rings (and meshes)**

Schedule:

Mission Benefits

DARPA

- U-resonator filter and MEMS switches
- PBG: CDF and super-prism filters

Design and fab PBG add-drop filter array with MEMS switch

Demonstrate high speed micro-WDM\ switch concept

1999 2001 2003 2005

APPROVED FOR PUBLIC RELEASE, DISTRIBUTION UNLIMITED